Black tea is not significantly different from water in the maintenance of normal hydration in human subjects: results from a randomised controlled trial

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Abstract

There is a belief that caffeinated drinks, such as tea, may adversely affect hydration. This was investigated in a randomised controlled trial.

Healthy resting males (n 21) were recruited from the general population. Following 24 h of abstinence from caffeine, alcohol and vigorous physical activity, including a 10 h overnight fast, all men underwent four separate test days in a counter-balanced order with a 5 d washout in between. The test beverages, provided at regular intervals, were 4×240 ml black (i.e. regular) tea and 6×240 ml black tea, providing 168 or 252 mg of caffeine. The controls were identical amounts of boiled water. The tea was prepared in a standardised way from tea bags and included 20 ml of semi-skimmed milk. All food taken during the 12 h intervention period was controlled, and subjects remained at rest. No other beverages were offered. Blood was sampled at 0, 1, 2, 4, 8 and 12 h, and a 24 h urine sample was collected. Outcome variables were whole blood cell count, Na, K, bicarbonate, total protein, urea, creatinine and osmolality for blood; and total volume, colour, Na, K, creatinine and osmolality for urine. Although data for all twenty-one participants were included in the analysis (mean age 36 years and mean BMI 25·8 kg/m²), nineteen men completed all conditions. Statistical analysis, using a factorial ANOVA approach within PROC MIXED, revealed no significant differences between tea and water for any of the mean blood or urine measurements. It was concluded that black tea, in the amounts studied, offered similar hydrating properties to water.

Key words: Tea; Hydration; Caffeine

It is often claimed in the media that caffeinated drinks, such as tea, can adversely affect normal hydration. Messages to drink a glass of water alongside caffeinated beverages to allow for possible diuretic effects have even featured in public health advice(1,2). Caffeine (1,3,7-trimethylxanthine) is a methylxanthine compound found naturally in coffee, tea, chocolate and cola. It can be added to supplements, energy drinks and some medicines(3). Caffeine is rapidly absorbed from the gastrointestinal tract, with plasma levels peaking at 60–90 min post-ingestion. It is mainly metabolised in the liver by the P450 enzyme system, producing a range of metabolites including dimethylxanthine, monomethylxanthine and uric acid⁴. The average half-life of caffeine is 2.5–4.5 h but can vary from 1 to 10 h in certain individuals(4). Acute studies on caffeine pills⁵,⁶ have reported modest diuretic effects at caffeine intakes of 5.6–8.75 mg/kg body weight (i.e. 370–612 mg/d for an average 70 kg person). However, research on caffeine pills does not relate directly to tea consumption for two reasons. First, tea is a complex substance containing flavonoids, theanine and phenolic acids, as well as methylxanthines, i.e. caffeine, theobromine, theophylline, xanthine, hypoxanthine and guanine⁸. Apart from caffeine, the other methylxanthines are present in prepared tea in very small quantities⁸ but may have diuretic effects⁹. Second, tea as consumed in the UK provides far less caffeine than is typically used in studies of caffeine pills. The National Diet and Nutrition Survey revealed that 77% of adults are regular tea consumers with a mean daily intake of 540 ml or 2.3 servings¹⁰. Assuming that a cup of tea contains 50 mg of caffeine, as estimated by the Food Standard Agency¹¹, this equates to a mean daily caffeine intake of 115 mg.

Few studies have examined the impact of caffeinated drinks on normal hydration, but all have reported no adverse effects on hydration. Grandjean et al.¹² compared 24 h consumption of water, cola and coffee in a randomised, controlled, cross-over trial (n 18 sedentary adults). Results

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showed no significant differences between the drinks in terms of the participants’ mean body weight, urine volume, specific gravity, creatinine and osmolality. Neither were there any significant differences in serum measurements of electrolytes, haematocrit, osmolality, creatinine, urea or protein. The average caffeine intake over 24 h ranged from 114 to 253 mg (or from 1·4 to 3·13 mg/kg body weight). Fiala et al.\(^{(13)}\) tested ad libitum caffeinated v. non-caffeinated cola over 3 d (\(n = 10\)) using a randomised cross-over design. During the trial, participants were physically active for 4 h/d. Apart from a significant difference in urine colour, there were no differences in urine or blood measurements of hydration. The average daily caffeine intake in the caffeinated condition was 245 mg. The findings from these trials are similar to those reported by the lower-dose caffeine pill studies.

Only one study has examined the influence of tea on hydration\(^{(14)}\), but this was undertaken at altitude. Participants (\(n = 13\)) were members of an expedition at Mount Everest Base Camp and consumed either ad libitum tea or water for 24 h. Urine samples were measured in order to assess fluid balance, but these revealed no significant differences in specific gravity, electrolyte balance (K\(^{+}\) and Na\(^{+}\)) or urine colour between the tea and water conditions. However, that study did not follow a controlled randomised design, and the influence of altitude makes it difficult to translate the findings to the general population.

Therefore, data are lacking on how tea, as consumed, has an impact on the hydration of sedentary human subjects. The aim of the present trial was to assess the impact of four or six servings of black (i.e. regular) tea on blood and urine measurements of hydration v. a water control.

**Methods**

The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Reading Independent Ethics Committee. Written informed consent was obtained from all subjects.

**Experimental design**

The study was a single-centre, randomised, controlled, cross-over trial to assess body hydration following consumption of black tea against a water control in healthy sedentary male volunteers. Tea intake was studied at two levels: four or six servings (as mugs). These levels were selected as they exceeded average tea intakes in the UK and would enable a thorough test of the model. Studies on caffeine pills usually provide a fixed amount of caffeine/kg body weight. However, as the present study was intended to be naturalistic, identical amounts of tea were given to all subjects regardless of body weight. The intervention was carried out during a 12 h controlled session for each beverage tested. Subjects and investigators were not blinded due to the obvious differences between the test and control beverages.

**Subjects**

Following the screening of thirty-three volunteers recruited from the Reading Scientific Services Limited (Reading, Berks, UK) volunteer panel by word of mouth or by public advertisement (January–March 2010), twenty-one healthy adult males were accepted into the study. Exclusion criteria were females, smokers, systemic medication likely to interfere with outcome variables, significant chronic illness, allergy or intolerance to tea or milk, excessive caffeine consumption (\(>10\) cups of coffee/d or equivalent), BMI <20 or >30 kg/m\(^2\) and concurrent participation in other food or clinical trials. Females were excluded due to a risk that the menstrual cycle may have an impact on fluid balance. The target sample size of twenty was selected based on previous hydration trials and was determined sufficient to detect any clinically relevant differences in hydration. A power calculation could not be made since the only published data on tea and hydration were collected at altitude as part of an uncontrolled trial\(^{(14)}\).

**Beverages provided**

In the present study, black tea was chosen as the test beverage because it is the most popular type consumed in Western countries\(^{(15)}\). Although black and green teas originate from the same plant, *Camellia sinensis*, the caffeine content of black tea leaves is slightly higher than that of green tea leaves (41·5–67·4 \(v.\) 32·5 mg/g\(^{(16)}\)). It was decided to add milk because this is a common way of preparing tea in the UK\(^{(16)}\), although no sugar was added as 63% of UK consumers drink tea unsweetened\(^{(17)}\).

Round tea bags, sourced from a nationally representative retailer, were prepared in a standardised way as follows: add tea bag to mug, add 230 ml freshly boiled water to the mug and stir the tea bag three times clockwise. Leave to brew for 40 s, stir further three times, squeeze the tea bag gently against the side of the mug and remove. Add 20 ml semi-skimmed milk. The total volume was 240 ml, which allowed for a 10 ml loss due to the removal of the tea bag and the addition of milk. The drinks were presented immediately after preparation. Boiled water, in identical amounts, was presented as the control beverage. This was allowed to cool slightly before consumption. Water was selected as the control, because it is viewed as an optimal fluid for hydration\(^{(1,2)}\).

The caffeine content of the tea beverage, as prepared by the standardised method, was measured using HPLC. This was found to be 16·7–21·1 mg/100 ml with an average of 18·9 mg/100 ml, giving an estimate of 42 mg for the caffeine content of one mug of tea (i.e. 220 ml of tea without addition of milk). This means that the four-mug protocol provided 168 mg of caffeine, while the six-mug protocol provided 252 mg of caffeine.

**Intervention in detail**

Fig. 1 gives an overview of the intervention. Participants were randomly assigned to complete four study days in counter-balanced order. Of the four study days, two were for the
black tea conditions (4 or 6 × 240 ml servings), while two were for the associated water conditions.

After abstaining from vigorous physical activity, alcohol and caffeinated drinks for 14 h in order to reduce the risk of dehydration before the trial, participants embarked on a 10 h overnight fast during which time only water was allowed. On entering the laboratory on each study day, baseline blood measurements were taken by a trained venepuncturist. Immediately afterwards, a test or control beverage was provided. Thereafter, beverages were offered at 2, 6 and 10 h for the four-serving protocol, and at 2, 4, 6, 8 and 10 h for the six-serving protocol. Subjects remained at rest during their time in the laboratory. Urine was collected for 24 h from arrival at the laboratory on each study day.

A standardised diet was offered during the 12 h of laboratory attendance. This consisted of a croissant at breakfast, 400 g mince and pasta bake at lunch and a round of sandwiches plus a slice of fruitcake at supper. For ethical reasons, participants were allowed to request a sip of water in addition to the test or control beverages. However, only one participant requested an additional sip of water during the four-serving tea condition. On leaving the laboratory, subjects were free to eat and drink without restriction.

After each study day, participants were given a 5 d washout period, during which time there were no restrictions other than those described in the exclusion criteria.

### Blood and urine analyses

Blood samples were taken by a trained venepuncturist at screening and then on each study day at baseline, 1, 2, 4, 8 and 12 h. At each time point, a 2 ml sample was collected in a tube with EDTA additive for haematology, and a 5 ml sample was collected in a SST™ tube with silica clot activator for biochemistry and serum osmolality. These were transported in a chilled state for analysis by The Doctors Laboratory (London, UK). Samples were analysed for the following parameters: total volume, electrolyte concentration, creatinine using the Roche/Hitachi Modular® P800 module (Hitachi Limited) and osmolality using the Advanced® Model 3320 Micro-Osmometer (Advanced Instruments, Inc.).

We collected 24 h urine samples at screening and then on each study day. Samples were analysed for the following parameters: total volume, electrolyte concentration, creatinine using the Roche/Hitachi Modular® P800 module (Hitachi Limited) and osmolality using the Advanced® Model 3320 Micro-Osmometer (Advanced Instruments, Inc.). A 20 ml aliquot was removed from the 24 h urine collection for the assessment of K, Na and creatinine. A 20 ml sample of mid-stream urine was also taken for the assessment of colour. This was coded as following: 1, colourless; 2, light yellow; 3, yellow; 4, dark yellow. This coding method was not validated.

### Statistical analysis

Data for all twenty-one participants were analysed in an intention-to-treat model. The urine measurements were analysed using a factorial ANOVA approach within PROC MIXED using SAS software (SAS Institute, Inc., Cary, NC, USA). Fixed factors in the model included beverage (tea v. water), protocol (four v. six mugs) and visit (participants attended the laboratory on four occasions during the intervention period), while the subjects were modelled as a random factor. The interactions ‘beverage × protocol’, ‘beverage × visit’ and ‘protocol × visit’ were also considered.

The urine measurements at screening were entered as covariates into the model to allow for the fact that different subjects were likely to have different baseline urine measurements. Blood measurements were analysed using a very similar approach to the urine measurements, with the additional step that data from time points at 1, 2, 4, 8 and 12 h were modelled using the repeated-measures facility within PROC MIXED. Measurements over each 12 h experimental period were likely to be mutually correlated with each other, and it was anticipated that an autocorrelation or ante-dependence covariance structure was the most appropriate for the data.

### Results

Although data for all twenty-one participants were included in the analysis, nineteen men completed all conditions. At baseline, mean age was 36 (20–54) years, mean weight was 81·8 (66–97) kg and mean BMI was 25·8 (22–30) kg/m². Of the nineteen men, seventeen were Caucasian. Using baseline weight and measured caffeine levels in the test beverage, average caffeine intakes in the four-mug protocol were 2·07 mg/kg body weight (range 1·73–2·55) mg/kg, and in the six-mug protocol were 3·11 mg/kg body weight (range 2·6–3·82) mg/kg.
### Table 1. Blood results for the four- and six-serving protocols*  
(Mean values with their standard errors, n 19)

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Baseline blood results revealed that all measurements were within normal ranges, indicating that the subjects were not dehydrated at the start of the study day. The statistical analysis of the blood parameters indicated no significant differences in body hydration after consuming water or tea beverages for either the four- or six-serving protocol. None of the interactions, i.e. ‘beverage × protocol’, ‘beverage × visit’ and ‘protocol × visit’, was statistically significant. Blood results for the six-mug protocol are shown in Table 1. The urine results indicated that there were no significant differences in body hydration after consuming water or tea beverages for either the four- or the six-serving protocol. The only significant finding was that urine colour was associated with the visit ($F = 6.21; P \leq 0.05$), in that urine colour was darker on visits 3 and 4 compared with visits 1 and 2. This suggests that participants may have consumed less fluid outwith the intervention period on those dates. Or the finding could be spurious since the translation of urine colour into numerical values relies on human judgement. Again, none of the interactions mentioned earlier was statistically significant. Table 2 presents the 24h urine results for both the four- and six-mug protocols and the screening results for comparison.

Further analysis was carried out to assess how body weight influenced urine output by plotting 24h urine output against body weight for each protocol and calculating Pearson’s correlation coefficients. In both the water and tea conditions, urine output was slightly higher in the lighter subjects compared with the heavier subjects. The association between body weight and urine output reached statistical significance only for the six-mug tea protocol ($r^2 = 0.56; P = 0.005$). However, when the outlier (who was also the lightest subject at 66 kg) was omitted, the association became non-significant ($r = 0.39; P = 0.094$).

There were eleven adverse events reported by eleven subjects: three subjects reported bruising or haematoma associated with blood sampling; six subjects reported headaches; one reported cold; one reported nausea. It was determined by the study medic that none of the adverse events was related to the test or control beverages.

### Table 1. Continued

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<td>1.36</td>
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W4, water four-serving protocol; T4, tea four-serving protocol; W6, water six-serving protocol; T6, tea six-serving protocol; BUN, blood urea N.

* Mean values were not significantly different for all results between W4 and T4, and between W6 and T6 ($P > 0.05$).

### Discussion

Caffeine is believed to have an adverse effect on hydration because it increases blood flow to the kidneys and inhibits the re-absorption of Na, Ca and Mg, thus stimulating urine output. There is observational evidence that caffeine provokes the need to urinate by stimulating the bladder’s detrusor muscles, although this was not confirmed by a randomised controlled trial in women with detrusor overactivity. However, much of the evidence underpinning the diuretic theory...
Tea and hydration

Table 2. Urine results for the four- and six-serving protocols* (Mean values with their standard errors, n 19)

<table>
<thead>
<tr>
<th></th>
<th>Screening</th>
<th>W4</th>
<th>T4</th>
<th>W6</th>
<th>T6</th>
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<tr>
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<td>Mean SEM</td>
<td>Mean SEM</td>
<td>Mean SEM</td>
<td>Mean SEM</td>
<td>Mean SEM</td>
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<tr>
<td>Urine volume (ml)</td>
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<td>1228 110</td>
<td>1117 90</td>
<td>1458 130</td>
<td>1498 140</td>
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<td>Creatinine (mmol/24 h)</td>
<td>17-3 2.74</td>
<td>15-0 1.68</td>
<td>14-1 1-01</td>
<td>14-4 1-27</td>
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<td>Na (mmol/24 h)</td>
<td>107-7 14-8</td>
<td>107-5 12-4</td>
<td>106-1 8-6</td>
<td>104-7 14-1</td>
<td>124-9 10-7</td>
</tr>
<tr>
<td>K (mmol/24 h)</td>
<td>83 15-7</td>
<td>66-0 6-8</td>
<td>61-0 5-1</td>
<td>65-3 6-1</td>
<td>70-9 8-6</td>
</tr>
<tr>
<td>Osmolality (mOsmol/kg)</td>
<td>640 65-7</td>
<td>664 48-0</td>
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<td>637 63-4</td>
<td>581 47-3</td>
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<td>3 0-2</td>
<td>3 0-1</td>
<td>3 0-1</td>
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</tbody>
</table>

W4, water four-serving protocol; T4, tea four-serving protocol; W6, water six-serving protocol; T6, tea six-serving protocol. *Mean values were not significantly different for all results between W4 and T4, and between W6 and T6 (P<0.05).

The results show that while tea consumption may influence urine output, the impact is generally not significant compared to water consumption. The data suggest that the diuretic effect of tea, although present, is not as strong as that of water. This conclusion is consistent with previous findings that have demonstrated a slight increase in urine output following tea consumption, compared to water intake.

However, it is worth noting that the urine results showed a non-significant trend towards a higher mean 24 h Na level in the tea condition, which was due to higher Na levels in three of the lighter subjects. Therefore, it would be worth repeating this trial in a group of lighter subjects, e.g. women or adolescents, to investigate how tea consumption may influence urine output status. It is worth noting that no association between body weight and urine output was observed for the four-mug protocol, an amount which exceeds average daily tea consumption in the UK (i.e. 2.5 servings).

In a review of the evidence, Ruxton (3) described eight randomised controlled trials, which had assessed hydration following caffeine consumption. In five of these, daily caffeine intakes of 1.4–6 mg/kg body weight (98–420 mg/d for an average 70 kg person) did not adversely affect normal hydration (7,12,15,20,21). A notable example is the 5-d trial by Armstrong et al. (7) during which subjects consumed 3–6 mg/kg body weight as caffeine pills. The three remaining trials reported significantly increased urination following caffeine consumption (5,6,22), although in two of these, caffeine intakes were high at 8.75 mg/kg body weight or 642 mg/d. In addition, two trials outwith the review found no evidence of altered hydration following caffeine consumption combined with intense exercise. In the study by Millard-Stafford et al. (23), a beverage providing 195 mg caffeine/l was tested under warm, humid conditions, while Del Coso et al. (24) provided 6 mg/kg body weight of caffeine as pills during 120 min of cycling in the heat.

These studies, using a wide range of caffeine intakes and often physically active subjects under warm conditions, represent a thorough test of the impact of caffeine on normal hydration. However, they do not entirely reflect the likely impact of tea, which is a more complex substance. Nevertheless, the findings suggest that lower amounts of caffeine, as would be found in an average person’s intake of caffeinated beverages (10), are tolerated by the body and do not cause dehydration. This concurs with an earlier review by Maughan & Griffin (9), which concluded that the caffeine levels found in commonly consumed beverages probably have no diuretic action, although the authors have highlighted a lack of specific data on tea. The present trial, which provided 168 or 252 mg of caffeine as tea, addresses this gap and confirms Maughan & Griffin’s conclusions (9).

As with most trials, there were limitations, which should be noted. The main one was the lack of control of beverages consumed at the end of the laboratory period, which may have influenced the urine results, although not the blood results. Another limitation was the lack of information about room temperature in the laboratory, which, nevertheless, would have had a minimal impact on hydration. It would have been useful to measure blood over 24 h to give a better assessment of hydration, but this was not possible within funding and time constraints. Habituation to caffeine is thought to be an important factor (25), thus regular caffeine consumers may have responded differently to non-consumers of caffeine in terms of hydration and urine output. The methodology was designed to minimise any such impact by excluding high consumers of caffeine (>ten cups of coffee/d or equivalent) and instructing participants to avoid caffeinated drinks for 24 h before each study day. Given the average half-life of caffeine is 2.5–4.5 h (4), it is likely that all participants had excreted any previous caffeine before beginning the trial. It would have also been interesting to estimate habitual caffeine and Na intakes before the trial. Na consumption can influence blood and urine Na measurements, although we attempted to minimise variation in the present trial by providing identical meals during the 12 h intervention period and ensuring that subjects were fasted for 10 h before entering the laboratory. While the caffeine content of the tea provided in the trial was measured, levels of other methylxanthines that could have an impact on hydration were not, although these would not have varied in the test beverage due to the standardised preparation of the tea.

Tea is consumed by the majority of the UK adult population, particularly elderly people (10), thus health professional advice and media comment, which incorrectly identify tea as...
a diuretic, could be misleading and serve to drive consumption towards less healthy beverages. Tea is a rich source of flavonoids, which have been associated with a reduced risk of heart disease and stroke in epidemiological studies at intakes of about four cups/d\(^{26,27}\). In addition, experimental research has reported that exposure to tea flavonoids reduces LDL-cholesterol oxidation\(^{28,29}\) and improves flow-mediated dilatation\(^{30}\). Thus, tea could be considered a healthy choice of beverage.

Given the findings of the present trial that consumption of tea at either four or six servings/d had no adverse effects on hydration, it could be argued that public health advice relating to caffeinated drinks should be revised. Both the Food Standards Agency\(^{2}\) and the Royal College of Nursing\(^{1}\) currently suggest that tea and coffee can act as diuretics and infer that water should be drunk alongside caffeinated beverages to offset the potential for fluid losses. However, the average intake of tea in the UK is 540 ml/d\(^{10}\), which is far below the 1320 ml offered in the six-serving protocol of the present study. Thus, it is highly unlikely that most tea consumers would experience excessive diuresis. Indeed, the present trial indicates that the hydrating properties of water and tea are similar.

**Conclusions**

Tea and water offered similar hydrating properties at intakes of four to six servings/d, equating to 168 or 252 mg caffeine. Given that average intakes of tea in the UK are considerably lower than the levels tested in the present study, the risk of dehydration in response to regular tea consumption is minimal. Public health advice should be updated to reflect the true contribution of tea to fluid requirements.

**Acknowledgements**

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**References**


